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(54) Title: ALUMINIUM-BASED ALLOY AND METHOD OF FABRICATION OF SEMIPRODUCTS THEREOF

(57) Abstract: This invention relates to the field of metallurgy, in particular to high strength weldable alloy with low density, of aluminium-copper-lithium system. Said invention can be used in air- and spacecraft engineering. The suggested alloy comprises copper, lithium, zirconium, scandium, silicon, iron, beryllium, and at least one element from the group including magnesium, zinc, manganese, germanium, cerium, yttrium, titanium. Also there is suggested the method for fabrication of semiproducts' which method comprising heating the as-cast billet prior to rolling, hot rolling, solid solution treatment and water quenching, stretching and three-stage artificial ageing.

Aluminium – Based Alloy And Meth d f Fabricati n f Semiproducts There f

This invention relates to the field of metallurgy, in particular to high strength weldable alloys with low density, of aluminium-copper-lithium system, said invention can be used in air- and spacecraft engineering.

Well - known is the aluminium-based alloy comprising (mass %):

copper	2.6-3.3
lithium	1.8-2.3
zirconium	0.09-0.14
magnesium	≤0.1
manganese	≤0.1
chromium	≤0.05
nickel	≤0.003
cerium	≤0.005
titanium	≤0.02-0.06
silicon	≤0.1
iron	≤0.15
beryllium	0.008-0.1
aluminium	balance

(OST 1-90048-77)

The disadvantage of this alloy is its low weldability, reduced resistance to impact loading and low stability of mechanical properties in case of prolonged low-temperature heating.

The aluminium–based alloy with the following composition has been chosen as a prototype: (mass %)

copper	1.4-6.0
lithium	1.0-4.0
zirconium	0.02-0.3
titanium	0.01-0.15
boron	0.0002-0.07
cerium	0.005-0.15
iron	0.03-0.25
at least one element from the group including:	
neodymium	0.0002-0.1
scandium	0.01-0.35
vanadium	0.01-0.15
manganese	0.05-0.6
magnesium	0.6-2.0
aluminium	balance

(RU patent 1584414, C22C 21/12, 1988)

The disadvantage of this alloy is its reduced thermal stability, not high enough crack resistance, high anisotropy of properties, especially of elongation.

Well - known is the method of fabrication of semiproducts from alloys of Al-Cu-Li system, which method comprises heating of the billet at 470-537 °C, hot rolling (temperature of the metal at the end of the rolling process is not specified), hardening from 549 °C, stretching (Ɛ=2-8 %) and artificial ageing at 149 °C for 8-24 hours or at 162 °C for 36-72 hours, or at 190 °C for 18-36 hours.

(US Patent 4.806.174, C22F 1/04, 1989)

The shortcoming of this method is the low thermal stability of semiproducts' properties because of the residual supersaturation of the solid solution and its subsequent decomposition with precipitation of fine particles of hardening phases, and also the low elongation and crack resistance, all of which increases the danger of fracture in the course of service life.

The well - known method of fabrication of products from the alloy of Al-Cu-Li system is chosen as a prototype, which method comprising: heating the as-cast billet prior to deformation at 430-480 °C, deformation at rolling finish temperature of not less than 375 °C, hardening from $525^{\circ\pm5}$ C, stretching (ε=1,5-3,0 %) and artificial ageing $150^{\circ\pm5}$ C for 20-30 hours.

(Technological Recommendation for fabrication of plates from 1440 and 1450 alloys, TR 456-2/31-88, VILS, Moscow, 1988).

The disadvantage of this method is the wide range of mechanical properties' values due to wide interval of deformation temperatures and low thermal stability because of the residual supersaturation of solid solution after ageing.

The suggested aluminium-based alloy comprises (mass %):

copper	3.0-3.5
lithium	1.5-1.8
zirconium	0.05-0.12
scandium	0.06-0.12
silicon	0.02-0.15
iron	0.02-0.2
beryllium	0.0001-0.02
at least one element from the group including	
magnesium	0.1-0.6
zinc	0.01-1.0
manganese	0.05-0.5
germanium	0.02-0.2
cerium	0.05-0.2
yttrium	0.005-0.02
titanium	0.005-0.05
aluminium	balance

The Cu/Li ratio is in the range 1.9-2.3.

Also is suggested the method for fabrication of semiproducts, comprising heating of as-cast billet to 460-500 °C, deformation at temperature ≥ 400°C, water quenching from 525 °C, stretching (ε=1,5-3,0%), three-stage artificial ageing including:

I - 155-165 °C for 10-12 hours,
II - 180-190 °C for 2-5 hours,
III - 155-165 °C for 8-10 hours,

with subsequent cooling in a furnace to 90-100 °C with cooling rate 2-5 °C/hours and air cooling to room temperature.

The suggested method differs from the prototype in that the billet prior to deformation process, is heated to 460-500 °C, the deformation temperature is not less than 400 °C, and the artificial ageing process is performed in three stages: first at 155-165 °C for 10-12 hours, then at 180-190 °C for 2-5 hours and lastly at 155-165 °C for 8-10 hours; then is performed cooling to 90-100°C with cooling rate of 2-5 °C/hour and subsequent air cooling to room temperature.

The task of the present invention is the weight reduction of aircraft structures, the increase in their reliability and service life.

The technical result of the invention is the increase in plasticity, crack resistance, including the impact loading resistance, and also the increase in stability of mechanical properties in case of prolonged low-temperature heating.

The suggested composition of the alloy and the method of fabrication of semiproducts from said alloy ensure the necessary and sufficient saturation of the solid solution, allowing to achieve the high hardening effect at the expense of mainly fine T_1-phase (Al_2CuLi) precipitates without residual supersaturation of the solid solution with Li, and that results in practically complete thermal stability of the alloy in case of prolonged low - temperature heating.

Besides that, the volume fraction and the morphology of hardening precipitate particles on grain boundaries and inside grains are those, that they allow to achieve high strength and flowability as well as high plasticity, crack resistance and impact loading resistance.

Due to $Al_3(Zr, Sc)$ phase particles' precipitation, the suggested alloy composition provides the formation of uniform fine-grained structure in the ingot and in a welded seam, absence of recrystallization (including the adjacent-seam zone) and hence, good resistance to weld cracks.

Thus, the suggested alloy composition and method for fabrication semiproducts thereof, allow to achieve a complex of high mechanical properties and damage tolerance characteristics including good impact behavior due to favourable morphology of hardening precipitates of T_1-phase upon minimum residual supersaturation of solid solution, which results in high thermal stability. The alloy has low density and high modulus of elasticity. The combination of such properties ensures the weight saving (15%) and 25% increase in reliability and service life of the articles.

The example below is given to show the embodiment of the invention.

Example

The flat ingot (90x220 mm cross selection) were cast from 4 alloy by semi-continuous method. The compositions of said alloy are given in Table 1.

The homogenized ingots were heated in an electric furnace prior to rolling. Then the sheets of 7 mm thickness were rolled. The rolling schedule is shown in Table 2. The sheets were water quenched from 525 °C, then stretched with 2,5-3 % permanent set. The ageing was performed as follows:

1 stage – 160 °C, 10-12 hours
2 stage – 180 °C, 3-4 hours
3 stage – 160 °C, 8-10 hours.

The sheets made of the alloy-prototype were aged according to the suggested schedule and according to the method – prototype (150°C, 24 hours).

Some of the sheets (after ageing) were additionally heated at 115 °C, 254 hours, what equals to heating at 90 °C for 4000 hours when judging by the degree of structural changes and changes in properties.

The results of tests for mechanical properties determination are shown in Tables 3-4. The data given in said Tables evidently show that the suggested alloy and method for fabrication of semiproducts, thereof as compared with the prototypes, are superior in hot rolled sheets properties, namely in elongation – by 10 %, in fracture toughness - by 15 %, in specific impact energy – by 10 % while their ultimate strength and flowability are nearly the same.

The highest superiority was observed in thermal stability of properties after prolonged low-temperature heatings.

Thus, the properties of the sheets fabricated from the invented alloy by the invented method practically do not change. After heating nearly all the properties do not change by more than 2-5 %.

On the contrary, the alloy-prototype showed: the ultimate strength and flowability increased by 6 %, elongation reduced by 30 %, fracture toughness reduced by 7 %, the rate of fatigue crack growth increased by 10 %, impact resistance reduced by 5%.

The comparison of the properties evidently show, that the suggested alloy and method for fabrication of semiproducts thereof can provide structure weight reduction (owing to high strength and crack resistance) by not less than 15 % and increase in reliability and service life of articles by not less than 20 %.

Table 1.

Compositions of the alloys, mass %

Alloy	Composition	Cu	Li	Zr	Sc	Si	Fe	Be	Mg	Mn	Zn	Ce	Ti	Y	Al	Cu/Li
Invented	1	3,4	1,5	0,08	0,09	0,04	0,02	0,07	0,3	0,15	-	-	-	0,001	Bal.	2,26
	2	3,48	1,76	0,11	0,069	0,05	0,02	0,06	0,28	0,31	0,02	-	0,02	0,001	Bal.	1,98
	3	3,1	1,63	0,07	0,1	0,1	0,2	0,0001	0,56	0,3	-	0,1	0,02	-	Bal.	1,90
Prior Art (Prototype)	4	3,0	1,75	0,11	0,09	0,08	-	-	0,56	0,27	-	-	0,02	-	Bal.	1,71

Table 2.

Technological schedule of fabrication of the sheets.

Alloy	Composition	Temperature of billet heating prior to rolling, °C	Temperature of metal at rolling finish, °C	Permanent set at stretching, %	Ageing		
					1 stage	2 stage	3 stage
Invented	1	490	420	3,0	160 °C, 10h	180 °C, 3h	160 °C, 10h
	2	460	410	2,5	160 °C, 12h	180 °C, 4h	160 °C, 10h
	3	460	410	2,5	160 °C, 10h	180 °C, 3h	160 °C, 8h
Prior Art	4	480	400	2,8	160 °C, 10h	180 °C, 3h	160 °C, 10h
(Prototype)	4'	480	380	2,8	150 °C, 24h		

Note: 1) sheets of alloy 1-3 prior to stretching, were hardened from 525 °C, of alloy 4 – from 530 °C

2) 4' – ageing according to prototype method.

Table 3.

Mechanical properties of hot-rolled sheets in as-aged condition (longitudinal direction)

Alloy	Composition	UTS, MPa	YTS, MPa	Elongation, %	Critical* coefficient of stress intensity K_{co}, MPa√m ΔK=32 MPa√m	Fatigue crack growth rate dl/dN, mm/k cycl. ΔK=32 MPa√m	Specific impact energy under loading E, J/mm
Inventive	1	569	534	9,5	65,8	2,35	18,2
	2	657	542	9,1	64,3	2,4	17,6
	3	560	530	10,8	66,4	2,2	18,4
Prototype	4	570	540	8,9	58,6	3,68	16,1
	4'	550	523	12,8	69,2	2,6	16,9

*width of samples (w) – 160 mm

Table 4.

Mechanical properties of hot-rolled sheets after prolonged low-temperature heating (115 C, 254 hours)

Alloy	Composition	UTS, MPa	YTS, MPa	Elongation, %	Critical* coefficient of stress intensity K_{co}, MPa√m ΔK=32 MPa√m	Fatigue crack growth rate dl/dN, mm/k cycl. ΔK=32 MPa√m	Specific impact energy under loading E, J/mm
Inventive	1	570	534	9,5	64,5	2,07	18,0
	2	578	545	8,4	65,2	2,4	17,6
	3	565	532	10,6	67,2	2,1	18,5
Prototype	4	599	567	6,4	58,1	3,71	15,4
	4'	586	547	8,1	64,2	2,9	16,2

Claims

1. Aluminium-based alloy comprising copper, lithium, zirconium, scandium, iron and at least one element from the group including, magnesium, manganese, which alloy is characterized in that it additionally comprises silicon and beryllium and at least one element from the group including magnesium, manganese, zinc, germanium, yttrium, cerium, titanium, having the composition within the following ranges (mass %):

copper	3.0-3.5
lithium	1.5-1.8
zirconium	0.05-0.12
scandium	0.06-0.12
silicon	0.02-0.15
iron	0.02-0.2
beryllium	0.0001-0.02
at least one element from the group including	
magnesium	0.1-0.6
zinc	0.02-1.0
manganese	0.05-0.5
germanium	0.02-0.2
cerium	0.05-0.2
yttrium	0.005-0.02
titanium	0.005-0.05
aluminium	balance,

the Cu/Li ratio is in the range 1,9-2,3.

2. Method for fabrication of semiproducts from the alloy of claim 1, which method comprising heating of as-cast billet, hot deformation, solid solution treatment and water quenching, stretching, artificial ageing and final cooling, which method is characterized in that the billet

prior to deformation process, is heated to 460-500 °C, the deformation temperature is not less than 400 °C, and the artificial ageing its performed in three stages: first at 155-165 °C for 10-12 hours, then at 180-190 °C for 2-5 hours and lastly at 155-165 °C for 8-10 hours; then is performed cooling to 90-100 °C with cooling rate of 2-5 °C/hour and subsequent air cooling to room temperature.